HISTORY OF ULTRASOUND

- **1918 -** Sound Navigation and Ranging was used
- **Early 1950's** –Water bath immersion technique
- **Late 1950's** – First contact compound B-scanner
- **1970's –** Gray scale imaging
- **Mid 1970's** – Real time scanning systems
- **1980's** – Doppler technique

SOUND

- A mechanical energy
- Requires a vibrating object to produced
- Cannot travel through a vacuum

ULTRASOUND

- High frequency sound waves
- Above 20,000 cycles per second (20 kHz)
- Inaudible to humans
- Used to scan tissues of the body
- Ultrasound Pulse: 2-10 MHz
- Pulse Duration: 1 microsecond
- Pulse Repetition: 1000 times/second

AUDIBLE SOUND

- 16 Hz to 20,000 Hz

INFRASOUND

- Below 16 Hz

ULTRASOUND GENERATORS

TYPES OF ULTRASOUND WAVES

- Longitudinal/Compression Waves
- Transverse/Shear Waves
- Surface/Rayleigh Waves

ACOUSTIC VARIABLES

- **Period (T):** the time taken for one complete cycle to occur (s or µs)
- **Wavelength (λ):** length of space over which one cycle occurs (m or mm)
- **Amplitude (Depth):** the maximum displacement that occurs in an acoustic variable
- **Frequency:** cycle per second (Hz)
- **Velocity:** frequency times wavelength

PIEZOELECTRIC CRYSTALS

- Generate ultrasound waves
- Capable of changing electrical signals into mechanical (ultrasound) waves

PIEZOELECTRIC CRYSTAL AS TRANSMITTER OF SOUND

- Converting electrical energy into mechanical energy (sound)

PIEZOELECTRIC CRYSTAL AS TRANSMITTER OF SOUND

- Converting mechanical energy (sound) into electrical energy

NOTE:

- Small crystal diameter
  - Increased beam divergence
- Larger crystal diameter
  - Decreased beam divergence

DIFFERENT MODES OF ULTRASOUND

A-MODE

- Echoes are shows as peaks
- Distance between various structures can be measured
- Used to build two-dimensional B-mode image

B-MODE

- Two-dimensional images in which the echo amplitude is depicted as dots of different brightness

REAL-TIME

- Shows movement as it occurs

M-MODE

- Shows movement as a function of time
- Used in cardiac scanning

DOPPLER ULTRASOUND

- Demonstrates and measures blood flow

DOPPLER EFFECT

- The change in apparent frequency of a wave as a result of relative motion between the observer and the source
- **Stationary Reflector:** reflected echoes are the same as the transmitted waves
- **Reflector that Moves Closer:** reflected echoes are higher than the transmitted echoes
- **Reflector that Moves Away:** reflected echoes are lower than the transmitted echoes

BASIC TYPES OF DOPPLER ULTRASOUND UNIT

1.) Continuous Wave Doppler Unit

- Ultrasound is continuous
- Measures high velocities accurately

- No depth resolution

2.) Pulsed Wave Doppler Unit

- Ultrasound is transmitted in pulses
- With good depth resolution
- Measures the speed of the blood in a particular vessel
- Cannot measure high blood velocities in deep vessels
- High velocities may be wrongly displayed as low velocities

3.) Colour Doppler Unit

- Shows different flow-velocities in different colours

4.) Duplex Doppler System

- Combination of a B-mode and Doppler system
- Allows the Doppler beam to be directed accurately at any particular blood vessels

WAVE PROPAGATION

- The transmission and spread of ultrasound waves to different tissues
- **Average Propagation for Soft Tissues:** 1540 m/s
- **Average Propagation for Soft Tissues:** 4620 m/s

WAVELENGTH

- The length of a single cycle of the ultrasound wave
- Inversely proportional to the frequency
- Determines the resolution of the scanner
- Higher the frequency, the shorter the wavelength

FOCUSING

- Adjustment of the ultrasound beam
- To improve resolution
- May be electronic or by a lens attached to the transducer

AMPLIFICATION

- Done by the time-gain-compensation (TGC) amplier
- To compensate for ultrasound attenuation in any part of the body
- To improve the quality of the final image

BOUNDARIES

- The line at the periphery of two tissues which propagate ultrasound differently
- The zone of echoes at the interface

PIEZOELECTRIC EFFECT

- **Piezein** – *"press or pressure"*
- Ability of a material to generate an electrical charge un response to applied pressure

PIEZOELECTRIC MATERIALS

- Crystalline materials composed of dipolar molecules
- **Quartz** – naturally occurring crystals
- **Lead zirconate titanate** – man made ceramic
- **Natural Materials:**
    - Quartz
    - Tourmaline
    - Rochelle Salt
- **Synthetic Materials:**
    - Lead zirconate titanate (PZT)
    - Barium titanate
    - Lead metaniobate
    - Ammonium dihydrogen phosphate
    - Lithium sulphate

ACOUSTIC IMPEDANCE

- Property of a substance
- Describes how the particles of that substance behave when subjected to pressure wave
- High density substance – high acoustic impedance
- Low density substance – low acoustic impedance
- **Formula:** $Z=pc$
    - p = density of material (kg/m^3)
    - c = speed of sound (m/s)
    - Z = acoustic impedance (rayls)

SUBSTANCE	Z	SPEED (m/s)
Air	0.0004	330
Fat	1.38	1450
Water	1.48	1480
Blood	1.61	1570
Kidney	1.62	1560
Soft Tissue	1.63	1540
Liver	1.65	1550
Muscle	1.70	1580
Bone	7.80	3500
PZT (crystal)	30	3870

ACOUSTIC IMPEDANCE AND REFLECTION

- **Substances with same acoustic impedance:**
    - 100% energy transmission
    - No reflection
- **Substances with a small difference in acoustic impedance:**
    - 95% energy transmission
    - 5% reflection

- **Substances with a large difference in acoustic impedance:**
    - 1% energy transmission
    - 99% reflection

TRANSDUCER/PROBE

- A device which converts one form of energy to another
- Converts electrical energy into ultrasound waves and vice versa
- Contains piezoelectric crystals
    - Transmit ultrasound beam
    - Receive reflected echoes

TRANSDUCERS/SCANNING PROBES

- The most expensive part of any ultrasound unit

1.) Linear Array Transducer

- Parallel scan lines
- Rectangular field of view
- Vascular, small parts and musculoskeletal applications
- Above 4 MHz

2.) Sector/Curvilinear Array Transducer

- Provides wide field of view
- Most useful in abdominal and obstetric scanning
- Best suited to image deep lying structures
- 3.5 MHz

3.) Convex Transducer

- Wide fan-shaped
- Useful for all parts of the body
- Except for specialized echocardiography

4.) Phased Array Transducer

- Flat faced transducer
- Wide field of view
- useful in cardiac and cranial ultrasound

COMPONENTS AND CONSTUCTION OF A TYPICAL TRANSDUCER

1.) PHYSICAL HOUSING

- Contains all individual components
- Provides the necessary structural support
- Acts as an electrical and acoustic insulator

2.) ELECTRICAL CONNECTIONS

- Formed in front and back of the crystal
- Made of thin film of gold or silver

3.) PIEZOELECTRIC ELEMENTS

- Crystalline minerals that generate voltages when subjected to a mechanical force
- **Piezein** – *"to press or squeeze"*
- **Piezoelectric Effect** – discovered by Jacques and Pierre Curie
- Thinner Piezoelectric Materials
  - Higher resonant frequencies

FREQUENCY

- Affects the quality the ultrasound image
- Higher Frequency
  - Shorter wavelength
  - Better Resolution
  - Lower Penetration
  - Higher Absorption
- Lower Frequency
  - Longer wavelength
  - Poor Resolution
  - Higher Penetration
  - Lower Absorption

4.) BACKING/DAMPING MATERIALS

- Shortens the ultrasound pulse length
- Eliminates the vibrations from the back face
- Controls the length of vibrations from the front face
- Improves axial resolution
- **Materials:**
  - Plastic or epoxy resin
  - Cork
  - Rubber
  - Araldite loaded with tungsten powder

5.) ACOUSTIC LENS

- Reduce the beam width of the transducer
- Improve image resolution
- **Width of the Beam:** determines lateral resolution
- **Lateral Resolution:** the ability to resolve structure across or perpendicular to the beam axis
- **Materials:**
  - Aluminum
  - Perspex
  - Polystyrene

6.) IMPEDANCE MATCHING LAYER

- Sandwich between the piezoelectric crystal and the patient
- Chosen to improved transmission into the body

BANDWIDTH

- The range of frequencies contained within an ultrasound pulse
- **Wide Bandwidth:**
  - Shorter spatial pulse length
  - Wider range of frequency
- **Narrow Bandwidth:**
  - Longer spatial pulse length
  - Narrower range of frequency

CHOOSING THE APPOPRIATE TRANSDUCER

1.) Obstetric Ultrasound

- Linear or convex transducer
- 3.5 MHz: better in later pregnancy
- 5.0 MHz: best during early pregnancy
- Focused at 7-9 cm

2.) General Purpose Ultrasound

- Sector or convex transducer
- 3.5 MHz
- Focused at 7-9 cm

3.) Pediatric Ultrasound

- 5.0 MHz transducer: for children
- Focused at 5-7 cm
- Sector transducer of 7 MHz:
  - Neonatal brain scans
  - For adult testis and neck
- Focused at 4-5 cm

ULTRASOUND BEAM

- Area through which the sound energy emitted from the ultrasound transducer
- Three dimensional and symmetrical around its central axis

TWO REGIONS OF ULTRASOUND BEAM

1.) Near Field/Fresnel zone
2.) Far Field/Fraunhofer zone

- Increasing Frequency
  - Longer near field
  - Less far field divergence
- Narrow Crystal Diameter
  - Narrower near field
  - More far field divergence
- Thin Crystal
  - Decreased near field
  - Increased far field
- Thick Crystal
  - Increased near field
  - Decreased far field

BEAM INTENSITY

- The power (measured in watts) flowing through a unit area

SIDE LOBES/GRATING LOBES

- Lobes at various angles to the main beam
- Approximately 15% of the energy in the beam
- Cause a degradation of lateral resolution

BEAM WIDTH

- The dimension of the beam in the scan plane
- Affects the spatial resolution
- Narrow Beam Width
    - Better spatial resolution

SLICE THICKNESS

- Three dimensional volume displayed as a two dimensional image

RESOLUTION

- The ability of an imaging system to differentiate between structures
- **Spatial Resolution:** resolution in space
- **Contrast Resolution:** resolution of gray shades
- **Temporal Resolution:** resolution in time

SPATIAL RESOLUTION

- Detail Resolution
- The ability to display two structures situated close together as separate images
- **Higher Frequency:**
    - Better resolution
    - Lower penetrability
    - Higher absorption
- **Lower Frequency:**
    - Poor resolution
    - Higher penetrability
    - Lower absorption

TWO COMPONENTS OF SPATIAL RESOLUTION

1.) AXIAL RESOLUTION

- Longitudinal, Linear, Depth or Range
- The ability to distinguish two objects parallel to the ultrasound beam
- Depends upon the spatial pulse length and wavelength
- **Short Spatial Pulse Length:** good axial resolution
- **Longer Spatial Pulse Length:** poor axial resolution

2.) LATERAL RESOLUTION

- Azimuthal, Transverse, Angular or Horizontal

- The ability to distinguish two objects perpendicular to the ultrasound beam
- Depends upon the beam diameter
- **Smaller Beam Width:** better lateral resolution
- **Larger Beam Width:** poor lateral resolution

CONTRAST RESOLUTION

- The ability of the imaging system to differentiate between body tissue and display them as different shades of gray
- Optimized by using the correct overall gain

TEMPORAL RESOLUTION

- Frame Rate
- The ability of the imaging system to display events which occurs at different times as separated images
- **Higher Frame Rate:** better temporal resolution

ULTRASOUND INTERACTIONS AND ATTENUATIONS

ATTENUATION

- Decrease in the intensity and amplitude of the ultrasound waves as they pass through tissues
- **Unit:** decibels per centimeter

FIVE MAIN PROCESSES THAT CAUSE ATTENUATIONS

1.) ABSORPTION

- Occurs when ultrasound energy is lost to tissues by its conversion to heat
- Main factor causing attenuation
- **Higher Frequency:**
  - Greater amount of absorption
- **Bone:** higher absorption coefficient
- Increasing protein content gives increasing absorption
  - Blood –> Fat –> Nerve –> Muscle –> Skin –> Tendon –> Cartilage –> Bone
- **Best Absorption:** tendon, ligament, fascia, joint capsule & scar tissue

2.) REFLECTION

- Occurs when two large structure of significantly different acoustic impedance form an interface

- Occurs when a sound wave strikes an object that is larger than the wavelength

3.) SCATTERING

- Occurs when an ultrasound wave strikes a boundary or interface between two small structures
- Occurs when a sound wave strikes an object that is equal to or smaller than the wavelength

4.) REFRACTION

- Occurs when the beam encounters an interface between two different tissues at an oblique angle
- The beam will be deviated as it travels through the tissue
- Occurs due to difference in wave velocity across an interface between two materials

5.) DIVERGENCE

- Occurs when the beam travels through tissue and it will diverge due to diffraction effects

ULTRASOUND ARTIFACTS

- A structure in an image which does not directly correlate with actual tissue being scanned

1.) REVERBERATION

- Comet tail
- The production of spurious or false echoes due to repeated reflections between two interfaces with a high acoustic impedance mismatch
- The presence of two or more strong reflecting surfaces
- **Often occur at:**
  - Skin-transducer interface
  - Gas surface and transducer
- **Prevention/Elimination:**
  - Increase the amount of gel used
  - Used a stand-off gel pad
  - Reduce the gain
  - Move the position of the transducer

2.) ACOUSTIC SHADOWING

- Caused by highly attenuating structure
- **Often occur at:**
  - Soft tissue and gas
  - Soft tissue and bone or calculus
  - Calcified mass

3.) ACOUSTIC ENHANCEMENT

- Caused by weakly attenuating structures

- **Often occur at:**
    - Distal to fluid-filled urinary bladder, gallbladder or cyst
    - Fluid-filled mass

4.) EDGE SHADOWING

- Combination of refraction and reflection occurring at the edges of rounded structures

5.) BEAM WIDTH ARTIFACT

- Variations of all echoes returning to the transducer
- **Prevention/Elimination:**
    - Correct positioning of the focal zone

6.) SLICE THICKNESS ARTIFACT

- Occurs due to the thickness of the beam
- Dependent upon beam angulation
- **Often seen in:**
    - Transverse view of the urinary bladder
- Inherent characteristic of the transducer

7.) SIDE LOBE ARTIFACT

- Echoes generated by side lobes assumed by the transducer to have arisen form the central axis of the main lobe
- Appearance can give rise to a false diagnosis
- Inherent characteristic of the transducer

8.) MIRROR IMAGE ARTIFACT

- Caused by specular reflection of the beam at a large smooth interface
- **Often seen in:**
    - Fluid-air interface
    - Diaphragm

9.) DOUBLE IMAGE ARTIFACT

- Caused by refraction of the beam
- **Often occur at:**
    - Rectus abdominis muscle
- **Prevention/Elimination:**
    - Move the transducer slightly to one side to avoid the junction of rectus abdominis muscle

10.) EQUIPMENT-GENERATED ARTIFACT

- Caused by incorrect use of the equipment control

"Passing the Board Exam is your main purpose to learn"

05/13/14